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EXTERNAL OPERATIONS, MAINTENANCE AND REPAIR (OMR) MODE SELECTION CRITERIA

Contract NAS8-31454

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FOREWORD

This document presents the results of an eight month study performed by the Essex Corporation to develop external operations, maintenance and repair mode selection criteria for use by payload designers. The work was performed under Phase II of NASA-MSFC Contract NAS8-31454 sponsored by the Bio-Engineering Division, Life Sciences Office of NASA Headquarters, under the responsibility of Dr. Stanley Deutsch, Director. Technical direction for the effort was provided by Mr. Stephen B. Hall of the Preliminary Design Office of the Program Development Organization.

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ACRONYMS

AS	Automated Servicer
EMU	Extravehicular Mobility Unit
EOTS	Earth Orbital Teleoperator System
EVA	Extravehicular Activity
FSS	Flight Support Station (Used with MMU)
HEO	High Earth Orbit
IOS	Integrated Orbital Servicing
IVA	Intravehicular Activity
LEO	Low Earth Orbit
MMU	Manned Maneuvering Unit
MMUS	Manned Maneuvering Unit System
NRCC	National Research Council of Canada
OMR	Operations, Maintenance and Repair
PIDA	Payload Installation and Deployment Aid
PLSS	Portable Life Support System
SOP	Secondary Oxygen Pack
SRMS	Shuttle Remote Manipulator System
TBD	To Be Determined
TOBE	Teleoperator Bay Experiment

1.0 INTRODUCTION

1.1 BACKGROUND

An orbital servicing study recently completed by COMSAT concluded that on-orbit servicing is the most cost-effective method of maintaining satellite availability and that spacecraft can be designed to be serviceable on-orbit. While the study was directed primarily toward free flying automated payloads, the conclusions also apply to sortie payloads mounted in the shuttle cargo bay (reference 4). A study recently completed by TRW for SAMSO also concluded that the most cost effective method of providing high availability satellite service (>90%) is by the use of on-orbit maintenance and repair (reference 19).

Other payload servicing studies have identified specific payloads that may require operations, maintenance and repair activities on equipment located in the cargo bay, in the shuttle vicinity or in high earth orbit (HEO). Many of these tasks may be performed by the Shuttle Remote Manipulator System (SRMS) or an extravehicular activity (EVA) crewman, both of which will be provided on each shuttle flight. Some of the tasks could also be performed by automated servicers (AS), an Earth Orbital Teleoperator System (EOTS) or an EVA crewman using a Manned Maneuvering Unit (MMU).

1.2 OBJECTIVES

The overall purpose of this document is to provide data to payload personnel to aid in the selection of operation, maintenance and repair (OMR) modes to perform external payload support activities. The specific objectives of the document are:

- To present what is currently known concerning the capabilities and limitations of different modes for performing payload external OMR.
- To provide a method for assessing the respective capabilities of the various OMR modes and selecting the most appropriate mode for specific payload tasks.

Sections 3.0 through 7.0 present descriptions of five OMR modes in as much detail as current hardware definition will allow. These modes include:

- Extravehicular Activity (EVA)
- Manned Maneuvering Unit (MMU) - used in conjunction with EVA
- Shuttle Remote Manipulator System (SRMS)
- Automated Servicer (AS) - Tug or Cargo Bay Mounted
- Earth Orbital Teleoperator System (EOTS)

Section 8.0 presents the methodology for comparing specific task requirements with the OMR mode capabilities to select the most appropriate method of performing the task.

2.0 DESCRIPTION OF OMR MODES

The selection of an OMR mode to perform a particular payload task will depend primarily on the specific task requirements, the impact on the payload design and the user charge policies. The paragraphs below present broad descriptions of the OMR mode capabilities to help the payload designer determine which methods are feasible for a particular task. Detailed data for each OMR mode are also presented in Sections 3.0 through 7.0. Table 2-1 presents definitions of the six modes and Figure 2-1 presents a composite illustration of the equipment required.

Table 2-1: OMR Mode Definitions

EVA -	EXTRAVEHICULAR ACTIVITY, A PRESSURE SUITED CREWMAN OPERATING OUTSIDE THE PRESSURIZED VOLUME OF THE SPACECRAFT.
MMU -	MANNED MANEUVERING UNIT, AN EVA CREWMAN USING A PERSONAL PROPULSION SYSTEM FOR MANEUVERING NEAR THE ORBITER.
SRMS -	SHUTTLE REMOTE MANIPULATOR SYSTEM, THE MANIPULATOR ARM LOCATED IN THE CARGO BAY USED FOR SPACECRAFT DEPLOYMENT. EQUIPMENT SERVICING CAPABILITY MAY BE PROVIDED IF ADDITIONAL END EFFECTORS ARE USED.
BAY AS -	PAYLOAD BAY AUTOMATED SERVICER, AN AUTOMATED SERVICER MOUNTED IN THE CARGO BAY USED TO SERVICE AUTOMATED SPACECRAFT IN LOW EARTH ORBIT (LEO).
TUG AS -	TUG AUTOMATED SERVICER, AN AUTOMATED SERVICER MOUNTED ON A SPACE TUG USED TO SERVICE AUTOMATED SPACECRAFT IN HEO.
EOTS -	EARTH ORBITAL TELEOPERATOR SYSTEM, A TELEOPERATOR SYSTEM WITH ITS OWN PROPULSION SYSTEM USED TO SERVICE/REPAIR AUTOMATED SPACECRAFT IN LEO.

Extravehicular activity (EVA) consists of a crewman in a pressurized suit called the Extravehicular Mobility Unit, along with handrails, foot restraints, lights, tethers and tools. EVA is the most versatile of the OMR modes because of the flexibility of the crewman to perform unscheduled and contingency tasks. Typical EVA tasks from previous NASA programs include retrieval of film magazines, replacement of electrical components, inspection, solar panel deployment and thermal shield deployment. EVA tasks are limited to areas that can be reached with orbiter handrails or handrails

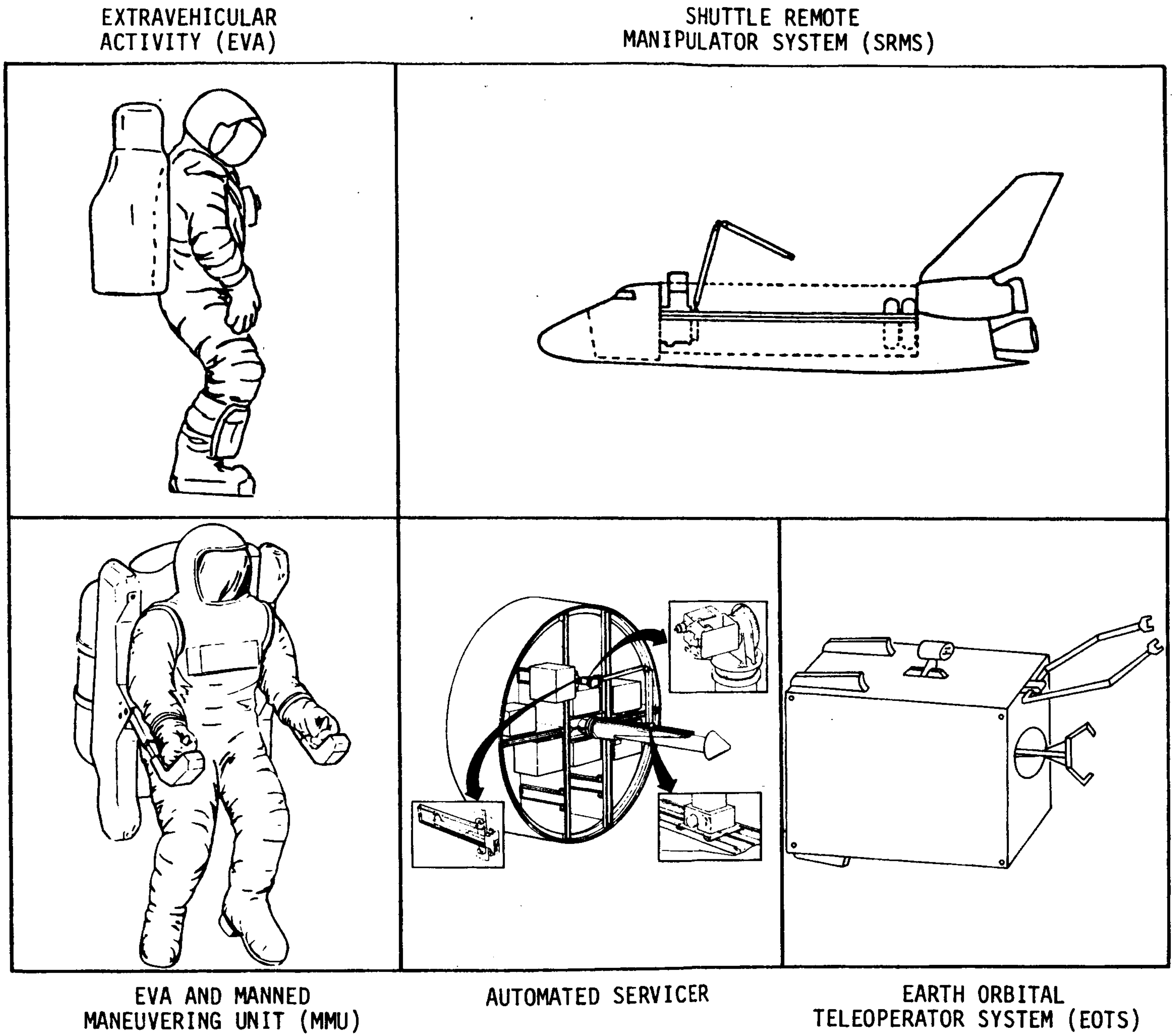

Figure 2-1: OMR Mode Composite

on the SRMS. Major inputs to the payload design include the addition of handrails to areas not accessible from the orbiter provided handrails and the provision of manually operable launch locks, doors, fasteners, etc. From a cost standpoint, EVA should be desirable for planned, unscheduled and contingency operations since the capability for two two-man EVAs is provided by the orbiter at no additional cost to the payload. Supplementary EVA equipment above the orbiter baseline provisions will be payload chargeable with respect to weight and volume.

The Manned Maneuvering Unit (MMU) is a personal cold gas propulsion system that can be used by an EVA crewman to translate to areas not accessible with the orbiter or SRMS handrails. The nominal operating range is 100 m. The MMU/EVA combination is ideal for inspecting or servicing unattached spacecraft in low earth orbit. One MMU will be flown on flights with planned EVA and an additional MMU will be flown on flights with a planned MMU/EVA. All MMUs flown for payload operations will be payload chargeable on a weight and volume basis.

The Shuttle Remote Manipulator System (SRMS) is a shuttle-attached manipulator provided by the shuttle for payload deployment and retrieval. The SRMS can possibly be used for package translation and module replacement although this capability will be a function of the final SRMS design and the end effectors that are provided. Payloads will be responsible for design, development, test and evaluation costs of any end effector designed for a specific payload task, and any special end effectors flown will be payload chargeable on a weight and volume basis.

Automated Servicers (AS) have been proposed as viable means of performing planned servicing operations on both LEO and HEO payloads. An automated servicer mounted in the cargo bay could service LEO satellites while servicing at HEO would require that the AS be attached to a Tug vehicle. Servicing would be limited to operations such as module replacement. Weight and volume of the servicer and supporting structure in the payload bay or on the Tug are chargeable to the payloads being serviced.

The EOTS is a manipulator system with a propulsion system, TV camera, and a payload docking capability which would operate in relatively close proximity to the shuttle and would be primarily involved in payload retrieval and servicing. The EOTS support system includes a crew station in the aft crew compartment of the shuttle and a storage and resupply station in the cargo bay. Servicing and retrieval with the EOTS would require payloads designed to interface with the EOTS, and weight and volume of the system would be chargeable to the payloads being serviced.

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3.0 EXTRAVEHICULAR ACTIVITY (EVA)

3.1 GENERAL DESCRIPTION

Without question, the most versatile and effective OMR mode employed in previous manned space missions has been EVA. The capabilities provided by the EVA crewmen saved Skylab from certain failure. The planned use of the EVA astronaut to retrieve film and experiments during the Skylab flights proved to be an efficient and relatively simple method of supporting Skylab experiments.

The capability for EVA will be provided on all shuttle flights. The EVA development cost is being borne by the shuttle and equipment for two two-man EVAs will be available for payload use at no additional cost. Additional EVA capability will be payload chargeable on a weight and volume basis.

The EVA system includes the man, the pressure suit, the portable life support system (PLSS), translation and restraint aids, and tools and support equipment. The pressure suit for shuttle EVA will be an advanced state-of-the-art suit with increased limb mobility and dexterity. It will be a 4.0 psi system which will require the crewman to pre-breathe for 3.5 hours prior to initiating actual EVA tasks. The suit is expected to provide good limb mobility due to the use of rotary bearing joints. Improvements have been made in the glove design such as the use of tucked fabric joints to improve dexterity of the fingers and hand.

The portable life support system (PLSS) provides breathing and pressurization gas for the suit as well as cooling for the crewman. The PLSS is a closed loop system with up to 6.5 hours oxygen supply. The system is rechargeable on-orbit. Two PLSSs will be provided on each shuttle flight.

The secondary oxygen pack (SOP) provides 30 minutes of emergency oxygen for the crewman in the event of a malfunction in the PLSS or if a high leak rate in the suit is encountered such as pressure relief valve failure.

The service and cooling umbilical provides the capability to recharge the PLSS on-orbit. It enables a total of four recharges (two per PLSS), allowing a total of three EVAs per PLSS since the PLSSs are launched full. Two of these are available for payload EVA and one is reserved for rescue operations.

Crew translation is accomplished through the use of handrails and handholds. Handrails will be provided by the orbiter along the payload bay door hinges and on the fore and aft bulkheads to enable access to most locations in the payload bay (Figure 3-1). Additional supplementary handholds will be

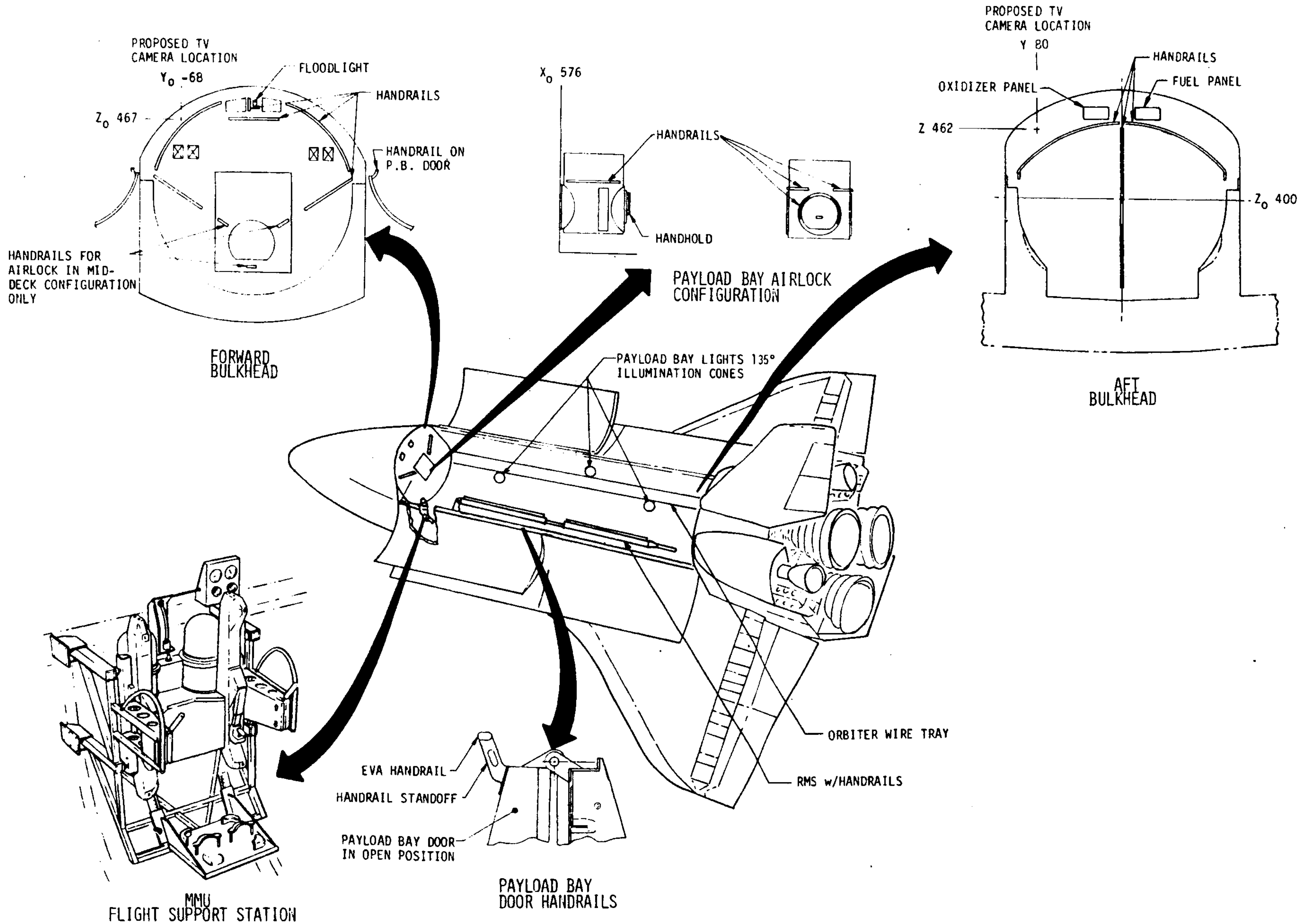
PROPOSED TV
CAMERA LOCATION
Y_0 -68
FLOODLIGHT
HANDRAILS
Z_0 467
HANDRAIL ON
P.B. DOOR
HANDRAILS FOR
AIRLOCK IN MID-
DECK CONFIGURATION
ONLY
FORWARD
BULKHEAD
X_0 576
HANDRAILS
HANDHOLD
PAYLOAD BAY AIRLOCK
CONFIGURATION
PROPOSED TV
CAMERA LOCATION
Y 80
HANDRAILS
OXIDIZER PANEL
FUEL PANEL
Z 462
Z_0 400
AFT
BULKHEAD
PAYLOAD BAY LIGHTS 135°
ILLUMINATION CONES
ORBITER WIRE TRAY
RMS w/HANDRAILS
EVA HANDRAIL
HANDRAIL STANDOFF
PAYLOAD BAY DOOR
IN OPEN POSITION
PAYLOAD BAY
DOOR HANDRAILS
MMU
FLIGHT SUPPORT STATION

Figure 3-1.

either fixed or portable and will be payload chargeable on a weight and volume basis. One concept for portable handholds includes the use of lightweight receptacles where a portable handhold can be installed. Handrails may also be provided along the SRMS for crew translation to various payload bay locations or to unattached automated spacecraft. The SRMS handrails may not only increase the domain of the EVA crewman but accomplish this at no additional cost to the payload. Cargo transfer systems include deployment booms and clotheslines. The film transfer task on Skylab was accomplished by means of an extendible boom 8 m in length on which the film magazines were mounted. The endless clothesline concept is a manually operated cargo transfer device. The clothesline was successfully used as an alternate film magazine transfer system on Skylab.

Common worksite aids that may have to be provided by the payload include handholds, restraints, lights, controls and displays, tools, replacement spares, tether attach points, equipment restraints, contamination or equipment/crewman protection shields and sufficient workspace to enable access to the equipment. Many of these equipment items were developed for Skylab and are available for payload applications (references 6 and 8).

3.2 SIGNIFICANT CAPABILITIES

The primary advantage of using EVA as a servicing mode is the flexibility of having a man at the worksite to evaluate the available information and perform the necessary operations to correct the problem. This flexibility will be enhanced by a set of standard tools provided by the shuttle for use by the payloads. These tools will allow the crewmen to perform both planned and unscheduled operations without requiring payload-furnished standard tools. The use of portable handrails and foot restraints may also enable the EVA crewman to establish a temporary workstation for unscheduled or contingency operations. The impact on the payload for providing these portable foot restraints and handrails will be the provision of lightweight receptacles at locations where EVA may be required.

A second major advantage of EVA is its minimum impact on the payload. The primary consideration in designing a payload for EVA is providing access to components that may need to be repaired or replaced. This is also desirable for ground maintenance and checkout. Lighting, handrails and tools are provided by shuttle and will be adequate for many payload EVA tasks. Additional equipment for specific payload operations would be provided by the payload.

3.3 MODE LIMITATIONS

The areas to be addressed during the design process if EVA is to be used include the following:

- <u>Mass Handling</u> - The precise limits of masses that can be handled in EVA depend on translation speeds, placement accuracy, mass moment of inertia and package size. JSC studies have reported that up to 3800 kg can be handled and controlled by an EVA crewman. Skylab crew debriefings indicate that handling masses while translating required suitable handrails and slow translating speeds.

- Impact on Payload Design - EVA imposes design requirements on the payloads, primarily in terms of providing lights, handrails, foot restraints and hand, body, visual and tool access for payload equipment operations. See reference 6 for specific design requirements.

- Time - EVA requires a 3.5 hour pre-breathe period prior to the actual EVA preparation, including suit donning. The first 1.5 hours can be spent in performing other mission operations while the crewman wears a portable mask.

- Workstation Location and Orientation - Care should be taken in the location and orientation of workstations due to the reach limitations of the restrained crewman in the suit. Handrails other than primary translation handrails may be required for the crewman to orient himself at the worksite.

- Contamination - Suit contamination will be from two sources - the thermal system sublimator and overall suit leakage. The sublimator will produce approximately 5.4 kg of H_2O per hour that has been filtered to one micron. The H_2O is vented to the rear of the PLSS away from the workstation. An umbilical could be developed to carry the H_2O away from the crewman and would be weight and volume chargeable to the payloads if flown. Suit leakage will occur primarily at the various joints and will be approximately 50 cc O_2 per hour.

3.4 SHUTTLE AND PAYLOAD SUPPORT REQUIRED

Support is required primarily in the provision of supplementary foot restraints, handrails, cargo transfer aids, lights, etc. Access to payload equipment will be required for visual, hand and tool access although this is generally required for ground operations. Additional checklists and component labels may be required on some external equipment with which the crewman may interface.

The SRMS and the Payload Installation and Deployment Aid (PIDA) may be useful to provide EVA crewman access to payloads and to position payload equipment for servicing (see Sections 5.1 and 5.2).

3.5 STATE OF DEVELOPMENT

EVA has been demonstrated on previous programs as an effective method of performing planned, unscheduled and contingency OMR tasks. The tools, crew restraints and various other support equipment developed for these programs will be applicable to many of the shuttle payloads. The EVA capability will be available on the first shuttle flight. The extravehicular mobility unit (EMU) is currently being designed and is scheduled for delivery in 1978. Cargo bay handrails are baselined and the foot restraints are designed and available for use. Specific tools provided by shuttle are TBD.

4.0 EVA AND MANNED MANEUVERING UNIT (MMU)

4.1 GENERAL DESCRIPTION

The Manned Maneuvering Unit System (MMUS) consists of the MMU and a Flight Support Station (FSS) (Figure 4-1). The MMU is an advancement of the Skylab flight experiment M509, Astronaut Maneuvering Equipment, which was flown successfully on Skylab in an IVA mode. The FSS is mounted in the payload bay and provides for storage and environmental protection of the MMU for launch, on-orbit, reentry and landing, facilitates pressure vessel recharge and battery changeout, and allows donning/doffing of the MMU by one EVA crewman.

The MMUS will be provided for shuttle and payload OMR tasks that require translation by an EVA crewman outside the cargo bay. Example tasks include payload deployment and retrieval, servicing of payloads outside the bay, assembly of structures and shuttle or payload inspection.

The MMU is a modular device designed to attach rigidly to the Portable Life Support System such that the EVA crewman, the EMU and the MMU form an integral man/machine system for EVA operations. The MMU contains a cold gas propulsion system, batteries, power conditioning, control electronics, gyros, hand controllers, and controls and displays required to provide the capability to translate an EVA crewman through free space in the vicinity of the shuttle. Mounting brackets are provided for ancillary equipment such as repair kits, cameras, lights, tools, etc. Two power outlets (28.0 $\pm$ 2.0 volts and 2.0 amps maximum) are available for the operation of ancillary equipment.

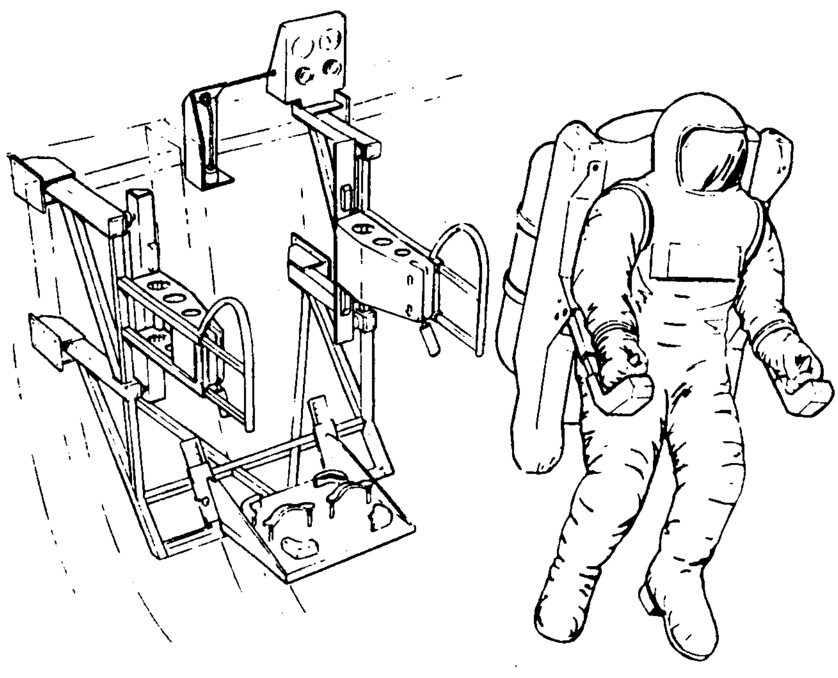

Figure 4-1: Manned Maneuvering Unit System

The MMU will provide six degrees of freedom translational capability with constant translational and rotational acceleration along any of the three axes in response to manual inputs and automatic attitude hold about any of the three axes. Translational acceleration will be 10.0 ± 1.5 cm/sec^2 and rotational acceleration will be 10.0 ± 3.0 deg/sec^2 in response to command inputs. The propulsion system is designed to use non-contaminating GN_2 and will provide a total delta velocity of 20 m/sec per charge, with recharge on-orbit as required. The MMU will support EVA operations for up to 6.5 hours with an operating range of up to 100 m from the orbiter.

Figures 4-2 and 4-3 show the envelope dimensions of the MMU and the FSS. The fully charged MMU will weigh 102 kg and the maximum weight of the FSS is 22.7 kg. Detailed specifications for the MMU are given in Reference 10.

4.2 SIGNIFICANT CAPABILITIES

The basic capability provided by the MMU is to extend the EVA crewman's mobility beyond the orbiter payload bay, without any attachment to the orbiter itself. Thus, with the translation capability provided by the MMU, the crewman is free to travel out to 100 m from the orbiter to perform payload servicing or inspection, orbital assembly and payload deployment and retrieval operations.

4.3 MODE LIMITATIONS

The following limitations apply to the EVA/MMU mode:

- Force/torque application capability limited to 0.55 - 0.83 kg-m while unrestrained (in automatic attitude hold mode)
- Increased volume requirements at worksite due to size of MMU (Figure 4-2)
- Operating range limited by total ΔV of 20 m/sec

4.4 SHUTTLE AND PAYLOAD SUPPORT REQUIRED

In addition to the orbiter baseline EVA provisions, stowage attachment provisions for the MMUS are provided in the payload bay. One MMU will be flown on flights with planned EVA and two MMUs will be carried when a MMU is required for payload support. Weight and volume for the MMUs flown in support of payload operations is chargeable to the payloads.

4.5 STATE OF DEVELOPMENT

Martin Marietta Denver Division is currently under contract to NASA JSC to perform a preliminary MMU design (Contract No. NAS9-14593, August 1976). A flight hardware procurement contract is scheduled to be awarded in October 1977 with the MMUS scheduled to be available for flight by December 1980.

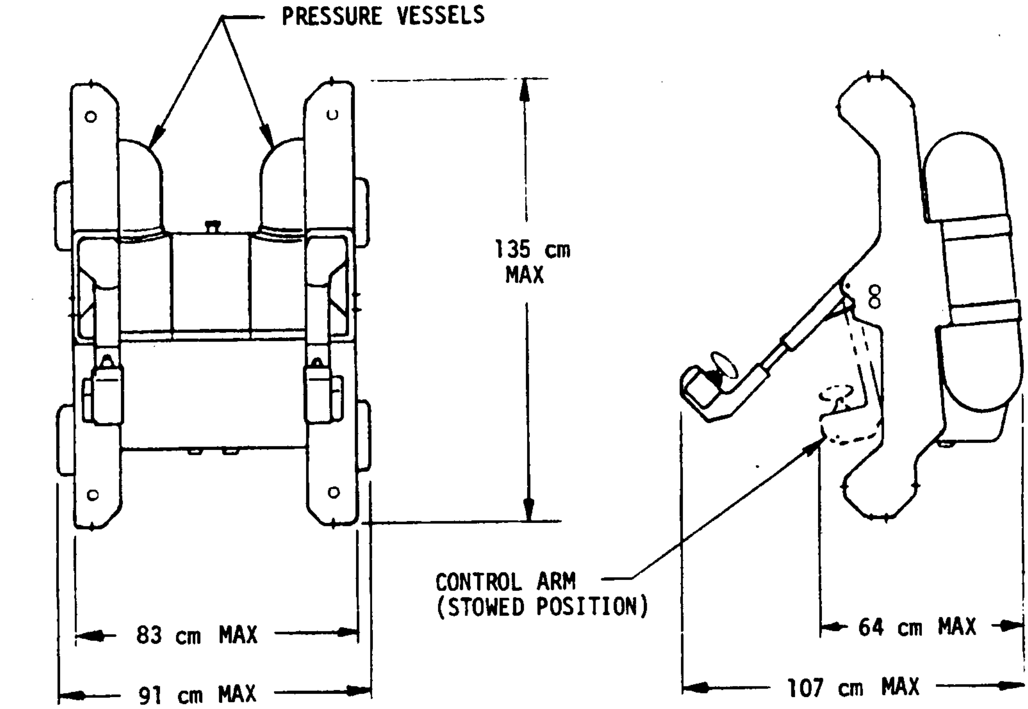

Figure 4-2: MMU Envelope Dimensions

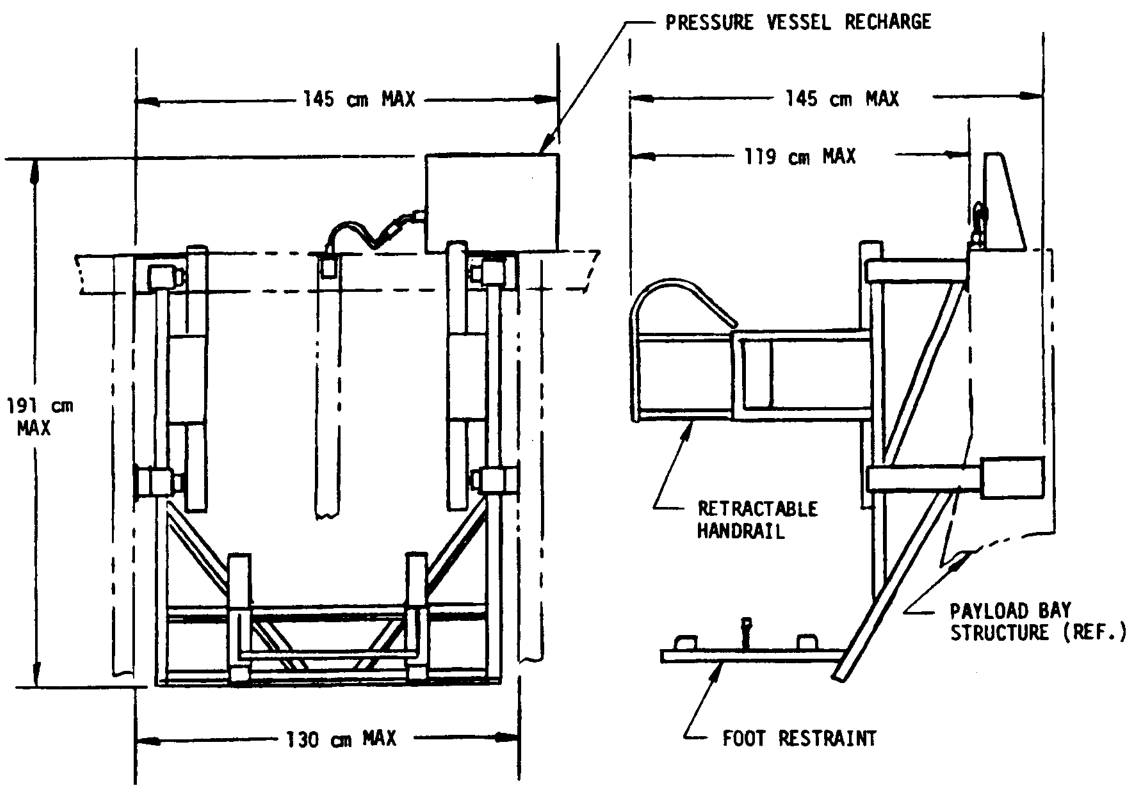

Figure 4-3: FSS Envelope Dimensions

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5.0 SHUTTLE REMOTE MANIPULATOR SYSTEM (SRMS)

5.1 GENERAL DESCRIPTION

The SRMS consists of a 15.24 m manipulator arm, removable end effectors, a control station located at the aft cabin rear bulkhead and associated video systems, lighting and control system hardware and software. The nominal SRMS consists of a single manipulator arm mounted on the forward port longeron and a Payload Installation and Deployment Aid (PIDA) mounted on the aft starboard longeron. On retrieval missions, the SRMS places the payload on the PIDA which swings it down into the bay. For deployment of a payload, the PIDA swings the payload out of the bay for removal by the SRMS. For EVA servicing of a payload, the PIDA might be used to position the payload since the PIDA will hold at intermediate positions.

A second SRMS manipulator can be mounted on the starboard longeron permitting operations requiring two manipulators. The second manipulator is payload weight chargeable (438.6 kg) and the PIDA cannot be flown on missions using two manipulators.

The SRMS manipulator is currently being designed as a six degree of freedom mechanism having shoulder yaw and pitch, elbow pitch and wrist pitch, yaw and roll. The segment diameter is 39 cm. Several pertinent design characteristics of the SRMS are:

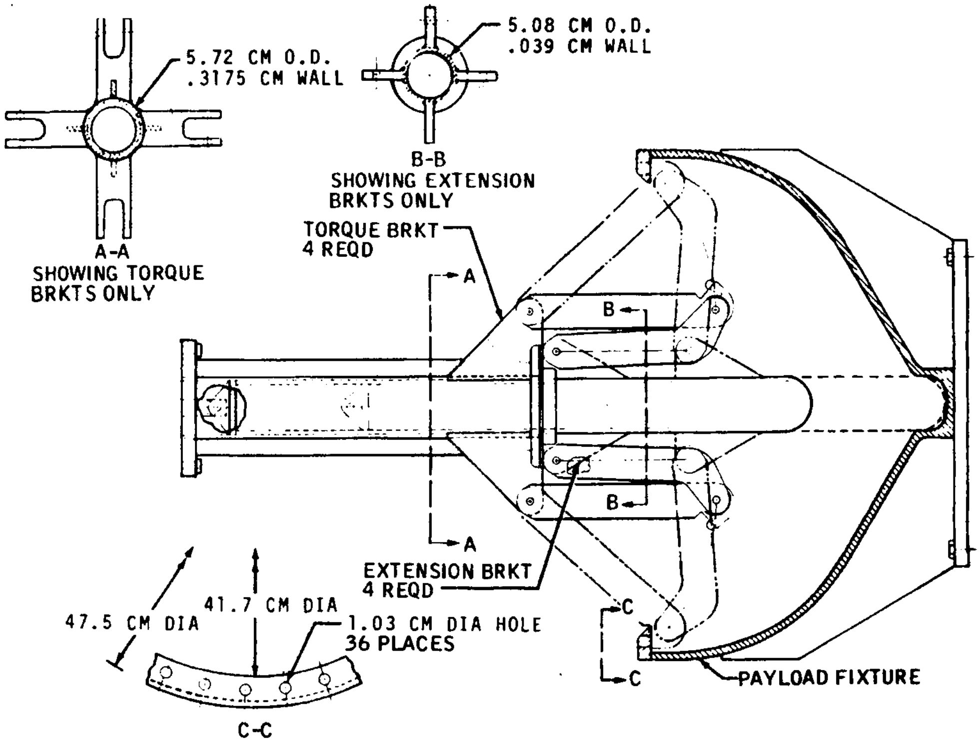
- Tip Force : 6.8 kg
- Tip Placement Accuracy : $\pm$ 3.8 cm
- Maximum Tip Velocity (Unloaded) : 60 cm/sec
- Maximum Tip Velocity (Loaded) : 6 cm/sec

The SRMS tip will be capable of stopping with a 14,500 kg payload within 0.6 m. The segment stiffness will result in a deflection of 0.56 cm per kg at the tip of the fully extended manipulator.

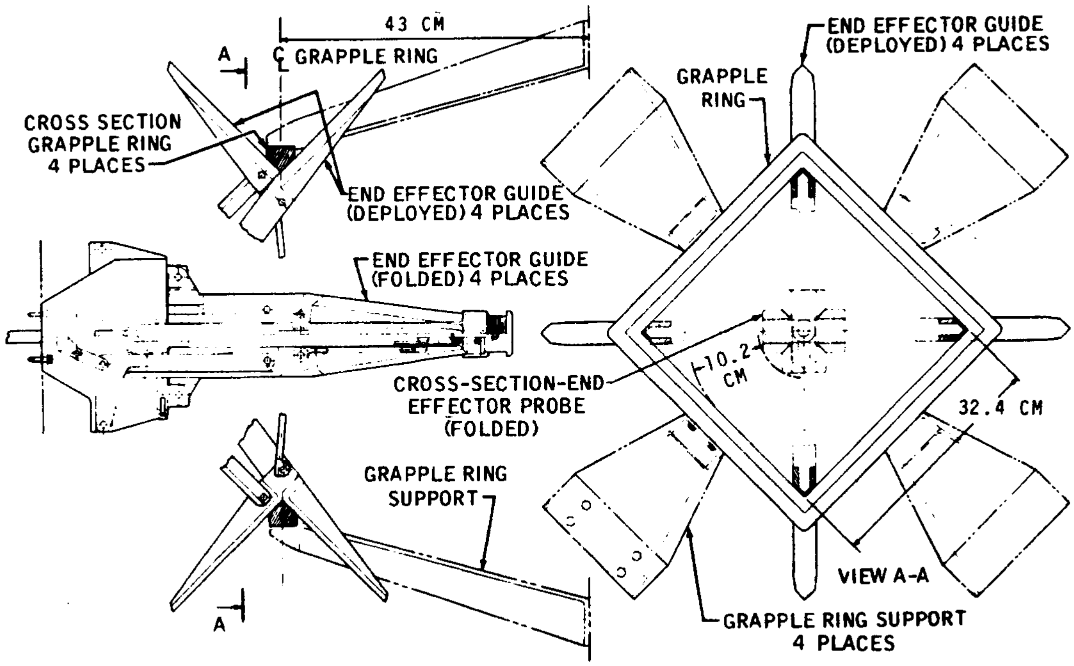
5.2 SIGNIFICANT CAPABILITIES

The primary function of the SRMS will be deployment and retrieval of automated payloads of up to 27,000 kg mass. While these requirements will drive the design, the SRMS may have some capability to perform servicing operations such as component replacement, and to provide a translation path for an EVA crewman.

The basic orbiter provided end effector will be optimized for grappling automated payloads. Two end effector concepts are shown in Figure 5-1. Additional special purpose end effectors for payload servicing operations could be provided by the user since the SRMS will be capable of end effector exchange during the mission. The SRMS segments will have orbiter provided EVA handrails to support EVA translation.



PROBE AND DROGUE END EFFECTOR CONCEPT



ICE TONG END EFFECTOR CONCEPT

Figure 5-1: SRMS End Effector Concepts

5.3 MODE LIMITATIONS

Specific SRMS limitations which are relevant to the use of the SRMS as an OMR mode are listed below:

- The reach envelope for the SRMS is determined by the segment lengths and joint limits. The segment dimensions and joint limits are shown in Figure 5-2. The resulting reach envelopes are shown in Figures 5-3 and 5-4.

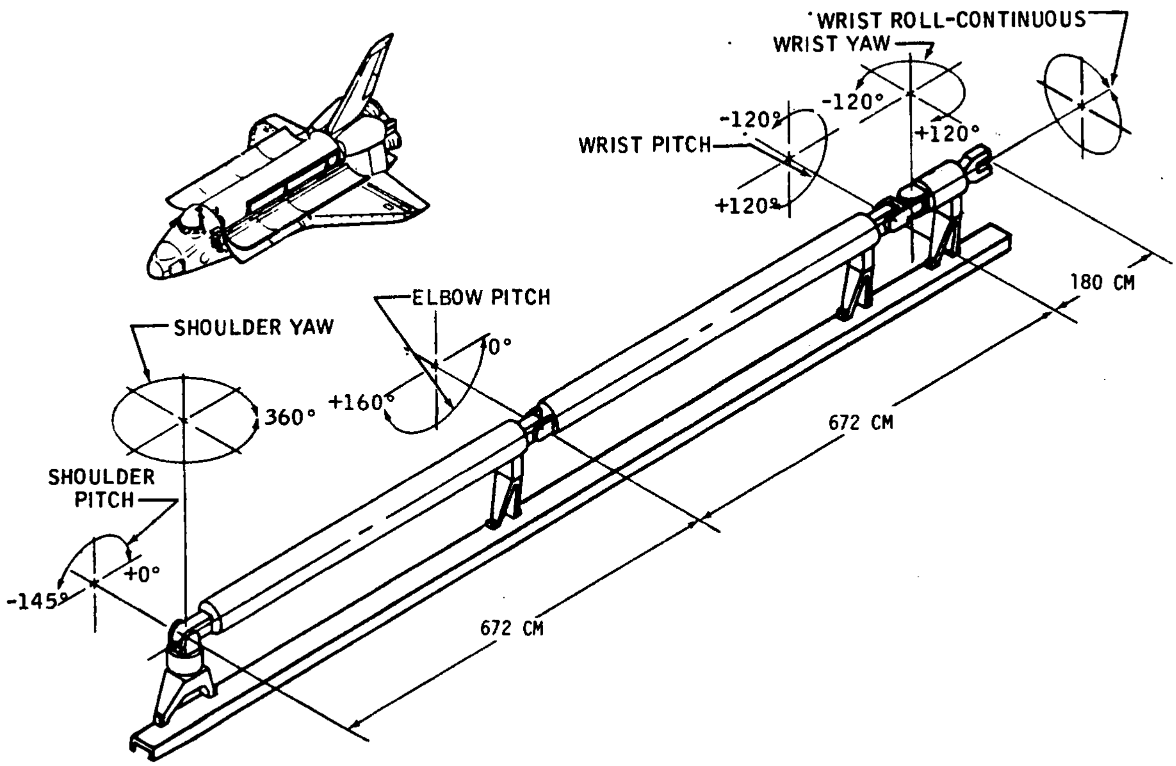


Figure 5-2: SRMS Segment Dimensions and Joint Limits

- Visual feedback to the SRMS operator will be provided by an overhead window and an aft bulkhead window whose fields of view are shown in Figure 5-4. Closed circuit TV will also be provided with one camera mounted on the SRMS wrist and one or more cameras mounted at selected locations in the bay. The current baseline visual system is 2-D, black and white, 525 line, and 30 frames/sec with pan, tilt and zoom.

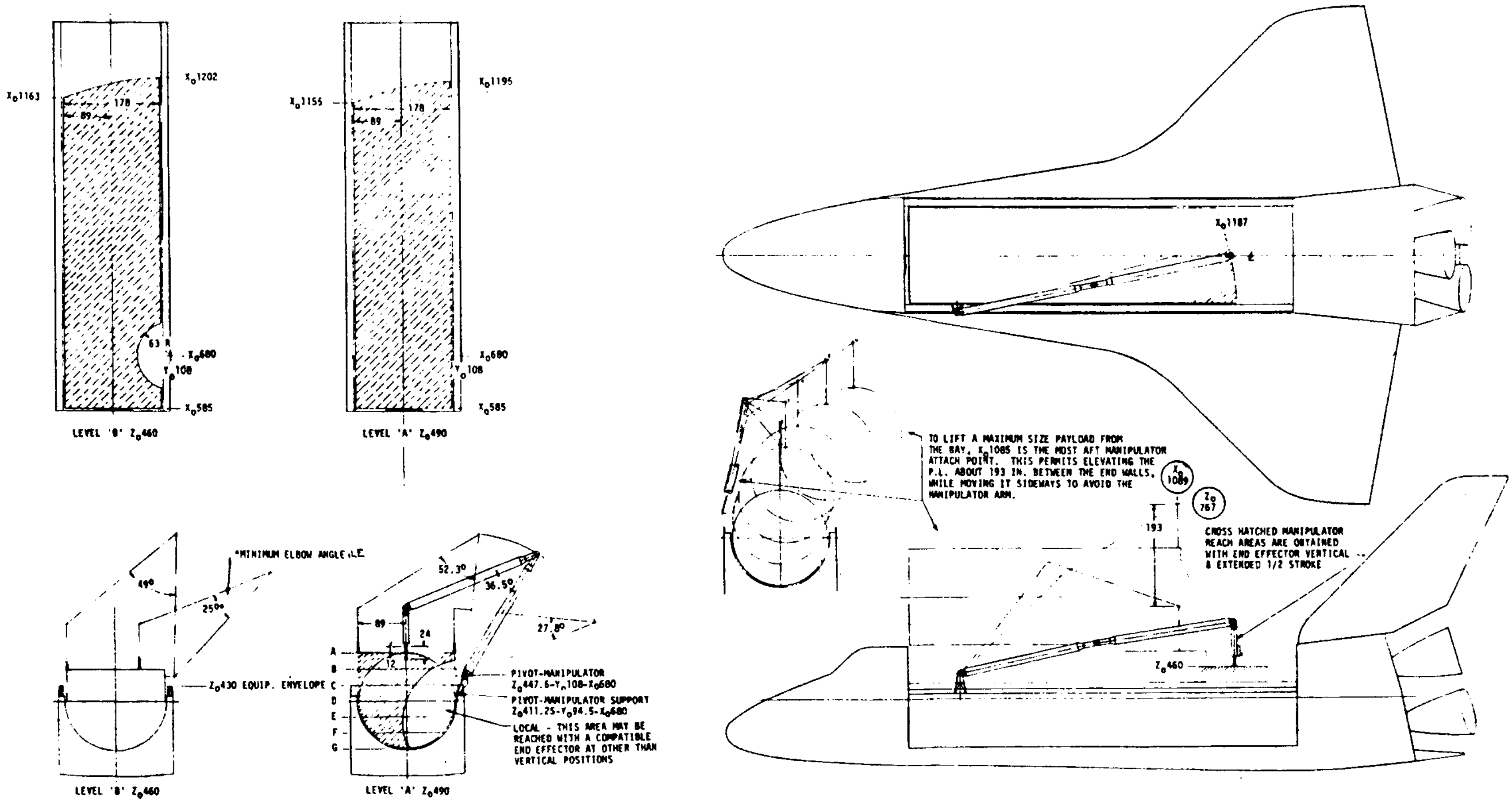


Figure 5-3: Payload Bay SRMS Reach Envelopes

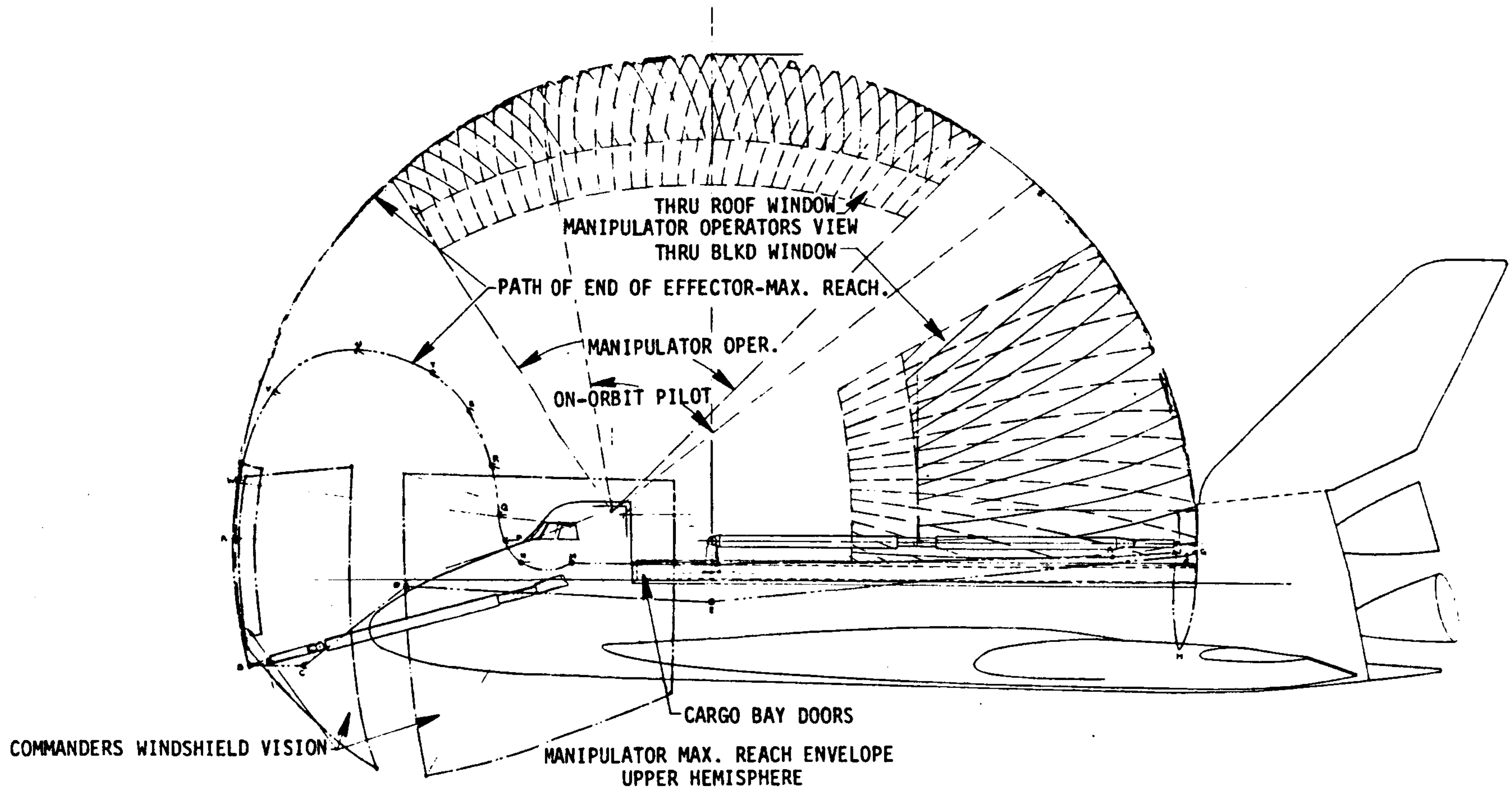


Figure 5-4: Upper Hemisphere SRMS Maximum Reach Envelope

- SRMS tip placement accuracy at the worksite will impact payload operations capability. The current design goal is $\pm$ 3.8 cm. Simulation studies are currently planned to evaluate the settling times and damping rates. These dexterity parameters will also depend on the position resolving and command abilities of the SRMS operator.

- The SRMS control system will be designed to avoid control singularities and extreme joint angles within the reach volume. These measures are designed to minimize the likelihood of control loss and damage potential. Further safety measures include rate limiting to ensure a 0.6 m stopping distance and collision avoidance software algorithms based on either a cargo bay software map or manipulator mounted proximity sensors.

- Force application capability of the SRMS is limited to 6.82 kg at the tip when the arm is fully extended. Force capability will generally increase as the lever arm from the shoulder to the end effector is shortened depending on the exact joint configuration. Force feedback is currently not baselined for the SRMS hand controllers.

- Mass handling and transfer by the SRMS can only be carried out between two points where attachments are provided to restrain the mass when it is released by the SRMS. Such attachments must be provided by the user and must positively attach the module to a receptacle while it is simultaneously attached to the SRMS.

5.4 SHUTTLE AND PAYLOAD SUPPORT REQUIRED

Movement of large masses by the SRMS will perturb the orbiter and RCS firings will produce oscillations in the SRMS. Depending on the degree of dexterity required, it may be necessary to suspend thruster firings during SRM operations. SRMS damage can also result if the thrusters are fired while the SRMS is attached to a large free mass on the order of the design mass of 14,500 kg. While the masses involved in payload operations do not appear like to approach this value, it should be noted that thruster firing abatement may required in some cases depending on the final structural characteristics of th SRMS.

Payloads which interface with the SRMS will need special attach points located to withstand the loads involved and which permit grasping by the gener purpose or special purpose end effectors. Module stowage devices and attach points will also be required. Shuttle support to the SRMS includes the aft cabin SRMS control station which may impact the space available for experiment controls and displays. Impacts to aft cabin space resulting from use of a second manipulator will be minimal since two manipulators will be controlled sequentially from one station.

5.5 STATE OF DEVELOPMENT

The responsibility for the development of the initial SRMS has been given to Canada, specifically the National Research Council of Canada (NRCC). NRCC has contracted with a Canadian team headed by SPAR Aerospace to actually develop the SRMS. The final end effector design should be selected by mid-1976. The development of a dexterous end effector is not being pursued at this time. The current schedule shows delivery of the flight article to NASA in mid-1979.

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6.0 AUTOMATED SERVICERS (AS)

6.1 GENERAL DESCRIPTION

In a study of integrated orbital servicing systems, Martin Marietta (NAS8-30820, August 1975) selected a pivoting arm on-orbit servicer (Figure 6-1) as the most effective and realistic automated servicer for performing sortie payload servicing in the cargo bay and automated payload servicing at HEO. The two major components of the servicer are (1) a pivoting arm servicer mechanism and (2) a stowage rack for module transport. The stowage rack has a diameter of 447 cm which is the same as the Tug outer skin. The pivoting arm assembly is a four degree of freedom manipulator (three translational and one rotational) and attaches to a mechanical splice fitting at the stowage rack center. The pivoting arm is designed to replace modules axially and has a linear operating length of 1.5 m. The system weighs 290 kg and has a stowed length of 155 cm for Tug operations and 178 cm for orbiter applications.

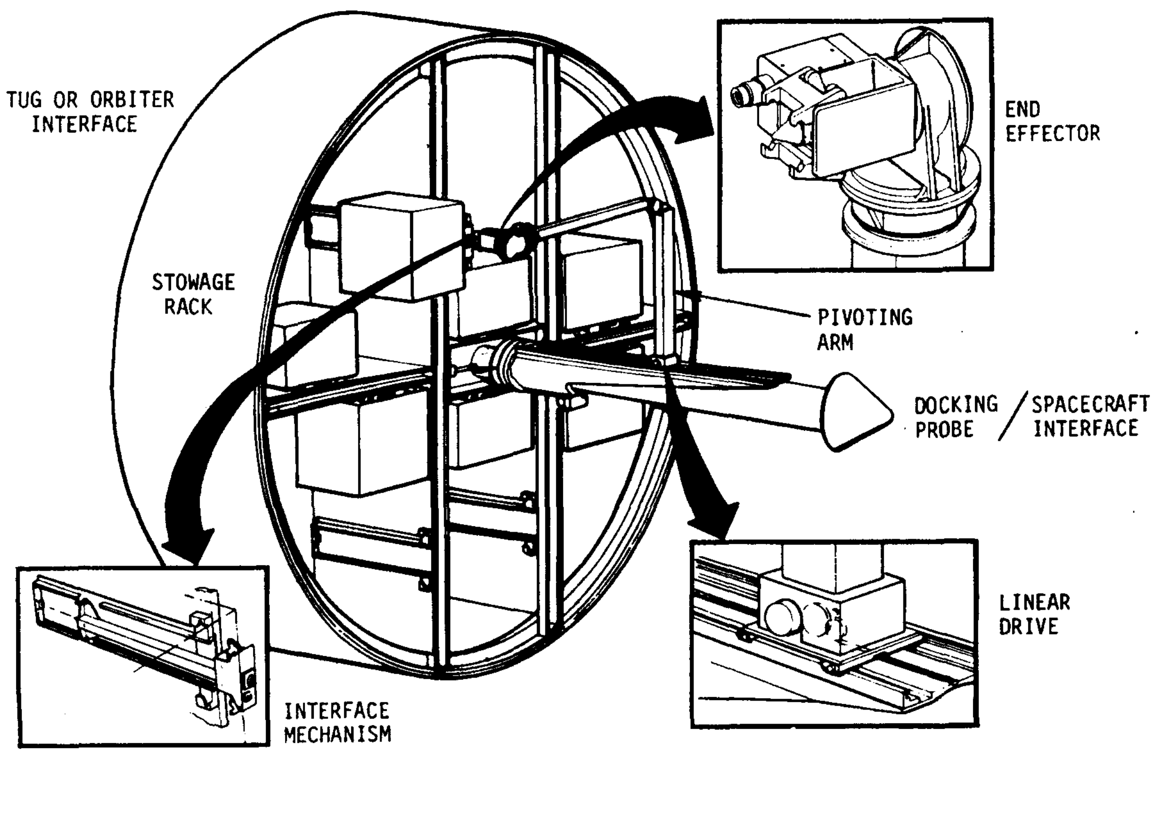

Figure 6-1: Pivoting Arm On-Orbit Servicer

6.2 SIGNIFICANT CAPABILITIES

The basic capabilities of the automated servicer include relatively rapid removal and replacement of large modules. The Martin study of Integrated Orbital Servicing (IOS) identifies requirements for the servicer to handle modules of up to 318 kg and to replace such modules within 10 minutes. Additional requirements identified in the MMC study include: tip force greater than 9 kg in worst configuration; minimum sliding friction areas; lifetime of five years; compatible with EVA; compensate for misalignments in six degrees of freedom; and light weight.

6.3 MODE LIMITATIONS

Limitations of the automated servicer mode are listed below:

- Servicer performs module exchange only.
- The spacecraft must be designed to be serviceable with all modules located in one or two separate docking faces or in one or two adjacent tiers which are accessible by the servicer.
- Pivoting arm replaces modules in an axial mode only. Capability for radial replacement could be designed into the servicer.
- Length of servicer (1.55 m stowed) occupies space otherwise usable by the payload and servicer weight subtracts from the capability of the Tug to take payloads to HEO. Weight and volume are chargeable to the payloads being serviced.
- For module replacement, latching devices will be required on both the module and the spacecraft frame. The weight for the complete latch assembly for a 106 cm cubic module is estimated to be approximately 7.5 kg. While the latch mass for a few large modules should be comparatively small, the total mass of latches for a large number of smaller modules may be a significant disadvantage.

The basic limitation of the automated servicer is its lack of flexibility Some degree of flexibility is obtained if the automated servicer is modified to be remotely controlled with a man-in-the-loop. With man-in-the-loop, some degree of flexibility is assured within the limits of the system itself.

6.4 SHUTTLE AND PAYLOAD SUPPORT REQUIRED

Support structure for mounting the servicer in the payload bay will be required and the spacecraft will require a docking mechanism to interface wit the docking probe on the servicer. All replaceable modules must be located on a docking face which is accessible to the automated servicer. Exchange module must be designed to interface with the stowage rack and the end effector on the pivoting arm.

6.5 STATE OF DEVELOPMENT

Martin Marietta is presently performing additional evaluation (Contract No. NAS8-30820) of the pivoting arm servicer to determine the impact of modifications to the servicer to enable it to perform more functions. Considerations include the addition of two more degrees of freedom to enable both radial and axial module exchange. Volumetric efficiency, control efficiency and spacecraft sensitivity to design changes are being studied. Trade studies using 4, 5 and 6 degree of freedom servicers are being performed. This work is scheduled for completion in April, 1977.

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7.0 EARTH ORBITAL TELEOPERATOR SYSTEM (EOTS)

7.1 GENERAL DESCRIPTION

The EOTS, originally designated the free flying teleoperator system, might serve a dual function during the shuttle programs: it may evolve as a possible OMR mode; and it is also a planned flight experiment designated Teleoperator Bay Experiment (TOBE). If developed, the EOTS vehicle would operate in relatively close proximity to the shuttle (within 3.2 km) and will be primarily involved in payload retrieval and servicing. The baseline vehicle is 1.2 x 1.8 x 1.2 m and has a propulsion system, TV camera, manipulator(s) and a payload docking capability. The EOTS support system includes a crew station in the aft crew compartment of the shuttle and a storage and resupply station in the cargo bay.

The EOTS manipulator system has a reach radius of 3 m. The propulsion system will provide a total ΔV of 30 m/sec. The video system will provide a stereo image to the operator for stereoptic viewing. The maximum individual mission duration will be assessed during the flight experiment.

7.2 SIGNIFICANT CAPABILITIES

The most significant application for the EOTS during the shuttle program will be the servicing of automated spacecraft that are not attached to the orbiter either by the SRMS or by launch locks in the cargo bay. This capability will be useful for servicing payloads that cannot be secured to the shuttle because of the following reasons:

- Unacceptable payload dynamic state
- Payload sensitive to orbiter contaminants
- Lightweight payload sensitive to orbiter thruster firings.

The actual operations to be performed on the automated payloads would be limited to inspection and module removal and replacement. Unscheduled operations would be severely limited since the payload components would have to be designed for interfacing with the EOTS manipulators.

7.3 MODE LIMITATIONS

The EOTS is primarily limited in where it can operate (cannot operate in the bay) and in its range capability (3.2 km from shuttle). Limitations also include possible contamination of sensitive payloads if the system propellant is hydrazine, and safety of the orbiter personnel when the EOTS vehicle is maneuvering close to the shuttle.

7.4 SHUTTLE AND PAYLOAD SUPPORT REQUIRED

To support the EOTS the orbiter must provide space and mounting structure for the tie-down and recharge station in the cargo bay, and the control station in the aft crew compartment. Payloads must be designed to be interfaced with the EOTS manipulator.

7.5 STATE OF DEVELOPMENT

Supporting research and technology activities on the EOTS are proceeding at MSFC primarily in the areas of visual systems and manipulator control concepts. The TOBE flight experiment is also under definition at MSFC. Actual development of a working EOTS for payload support is not being pursued.

8.0 OMR MODE SELECTION RATIONALE

In order to determine which OMR mode is best suited for a particular payload task, the designer must first identify the specific task requirements and then compare these requirements with the OMR mode capabilities. This section presents a general method for accomplishing these two steps and the detailed data needed for the task/mode capability comparisons. The simplified process is illustrated in Figure 8-1.

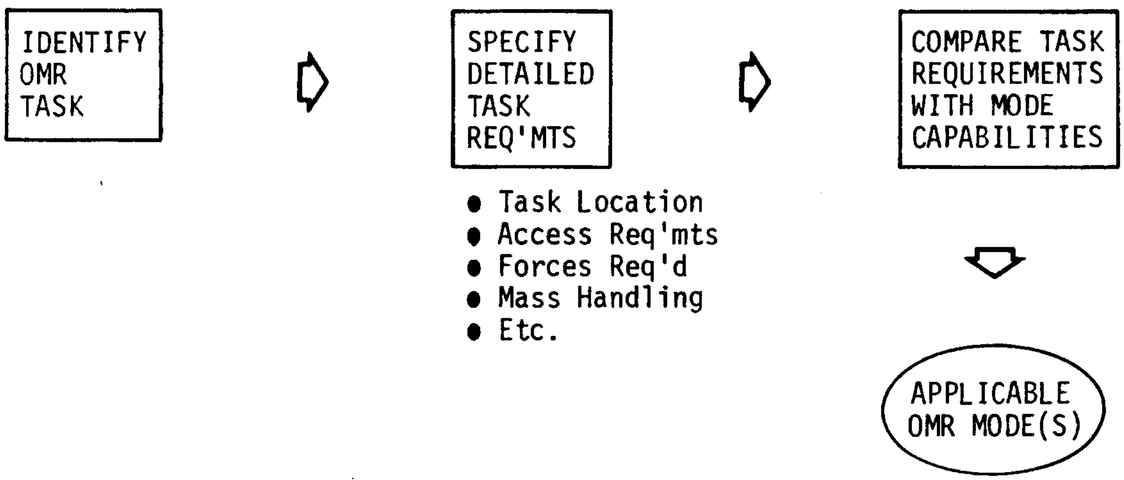


Figure 8-1: Simplified OMR Mode Selection Process

8.1 IDENTIFY OMR TASK

The first step in the OMR mode selection process is to define what external tasks may be performed. From the payload designer's viewpoint, requirements for OMR may arise because of a cost savings for servicing external components or because of an operational requirement for repairing or jettisoning a failed external component.

Payload cost savings may be realized by replacing limited life components near the end of their life cycle or repairing system components to extend an instrument's useful life. In some cases OMR can also be used to enhance data quality by calibrating an instrument or retrieving heat or radiation sensitive materials. OMR tasks justified on the basis of cost savings can be either planned or unscheduled operations.

OMR tasks may also be required to correct payload anomalies. These includ retracting failed-extended equipment, securing failed-loose hardware, jettisonir hazardous equipment or repairing failed pallet instruments. These tasks may not be required for cost savings or data enhancement but may be necessary to so more immediate problems such as closing the payload bay doors or securing loose equipment for landing. Every external payload component should be examined to identify the failure modes that could prevent safe return of the shuttle. Payloads with components that could cause contingency situations of this type shou be examined to identify the necessary OMR tasks to correct the potential proble

8.2 COMPARE PAYLOAD TASK REQUIREMENTS AND MODE CAPABILITIES

When the potential OMR tasks have been identified, the detailed task requirments should be defined for comparison with the OMR mode capabilities. These task requirments include such factors as where the task will be performed, time limitations, force exertion, mass handling and access problems. This informati should describe the tasks in as much detail as current payload definition will allow. Table 8-1 presents some of the data that should be specified in order t describe the payload tasks. The first column presents nine basic OMR task descriptions. Although this list may not be comprehensive for all possible tasks it includes all of the major data categories. The second column contains a breakdown of each of the data categories and presents the factors that will hav significant effect on the selection of a particular OMR mode.

For each of these mode selection factors, the appropriate OMR modes are identified in the third column. For example, if a payload has a potential unscheduled requirement for releasing a failed sun shield on the spacelab pallet, Data Category No. 1 (Task Location) indicates that since the task is in Low Ear Orbit and inside the cargo bay, the applicable OMR modes are EVA, the SRMS and the cargo bay Automated Servicer. Data Category No. 2 (OMR Task Type) also ind cates that the two applicable modes for unscheduled operations are EVA and the SRMS since these methods are provided by the shuttle for unscheduled and contingency operations on all flights. Data Category No. 4 (Dexterity Requirement narrows the choice to EVA since small hand tools may be required to release and retract the sun shield. By using the table in this manner, the payload designe can select the most appropriate OMR mode(s) for performing the external payload tasks.

8.3 OMR MODE SELECTION

To aid the payload designer in using Table 8-1 and obtaining more detailed information from the specific mode descriptions, a rationale is needed for addressing the most important questions first. For instance, where the task will be performed has more impact on mode selection than the force exertion requirements. A logical ordering of questions is presented in decision tree form in Figure 8-2 for the example task of retracting a failed-extended astromast boom. The most important task descriptors are:

Table 8-1: OMR Mode Selection Factors

DATA CATEGORY	MODE SELECTION FACTORS	CANDIDATE OMR MODES
TASK LOCATION	LEO - INSIDE CARGO BAY	EVA, BAY AS, SRMS
	LEO - OUTSIDE CARGO BAY, ATTACHED	EVA, MMU
	LEO - OUTSIDE CARGO BAY, UNATTACHED	MMU, SRMS, EOTS
	HEO	TUG AS
OMR TASK TYPE	PLANNED - PREPARED WORKSITE	ALL
	UNSCHEDULED - WORKSITE OK FOR SOME TASKS	EVA, SRMS
	CONTINGENCY - UNPREPARED WORKSITE	EVA, SRMS
ACCESS REQUIREMENTS (Visual, Body, Hand & Tool)	SUITABLE FOR EVA - SEE SECTION 3.0	EVA
	SUITABLE FOR EVA/MMU - SEE SECTION 4.0	MMU
	SUITABLE FOR SRMS - SEE SECTION 5.0	SRMS
	SUITABLE FOR AS - SEE SECTION 6.0	BAY AS, TUG AS
	SUITABLE FOR EOTS - SEE SECTION 7.0	EOTS
DEXTERITY REQUIREMENTS	MANIPULATE SMALL TOOLS & COMPONENTS	EVA, MMU
	HIGH PLACEMENT ACCURACY ($\leq$ 3 cm)	EVA, MMU, BAY AS, TUG AS
	OPERATIONS WITH DELICATE EQUIPMENT	EVA, MMU, BAY AS, TUG AS
	HANDLE LARGE OBJECTS ($\geq$ 10 cm)	ALL
	LOW PLACEMENT ACCURACY ($\geq$ 3 cm)	ALL
FLEXIBILITY REQUIREMENTS	HIGH - PERFORM UNSCHEDULED OPERATIONS	EVA, SRMS
	LOW - PERFORM ONLY PLANNED OPERATIONS	ALL
TIME CONSTRAINTS	IMMEDIATE OPNS ON PAYLOAD REQD	SRMS, EOTS, BAY AS, TUG AS
	3.5 HR PREBREATHE TIME ACCEPTABLE	ALL
MASS HANDLING	LESS THAN 8000 Kg	EVA (See Sect. 3.0), MMU (See Sect. 4.0), SRMS, TUG AS, BAY AS
	8000 Kg - 29,000 Kg	SRMS
FORCE APPLICATION	$\leq$ 7.0 Kg RMS	ALL
	$\leq$ 200 Kg EVA	EVA, MMU
	$\geq$ 200 Kg	BAY AS, TUG AS
CONTAMINATION CONSTRAINTS	SENSITIVE EQUIPMENT	ALL (See Section 3.0 for EVA contamination data)
	NONSENSITIVE EQUIPMENT	ALL
CREW/EQUIPMENT SAFETY	OPERATIONS NEAR HIGH VOLTAGE EQUIPMENT	ALL
	OPERATIONS NEAR HIGH PRESSURE VESSELS	ALL
	POSSIBLE CONTACT WITH FRAGILE OR SENSITIVE EQPMT.	ALL
	OPERATIONS IN HIGH RADIATION ENVIRONMENT	ALL (EVA & MMU may require special precautions)
	OPERATIONS IN HIGH/LOW TEMPERATURE ENVIRONMENT	ALL (EVA & MMU may require special precautions)
	OPERATIONS NEAR LOOSE MASSIVE EQUIPMENT	ALL

NOTE: Specific data for mode selection and tradeoffs can be found in Sections 3.0 through 7.0.

- Task Location : LEO-Inside Cargo Bay
- OMR Task Type : Unscheduled (No prepared worksite)
- Dexterity Requirements : Manipulate Small Tools
- Time Constraints : None
- Mass Handling : Less Than 20 kg
- Access Requirements : Tool Access Required Between Adjacent Components 16 cm Apart

The simplified decision tree represents the logical thought process that should be used by the payload designer to select the best OMR mode for the particular task.

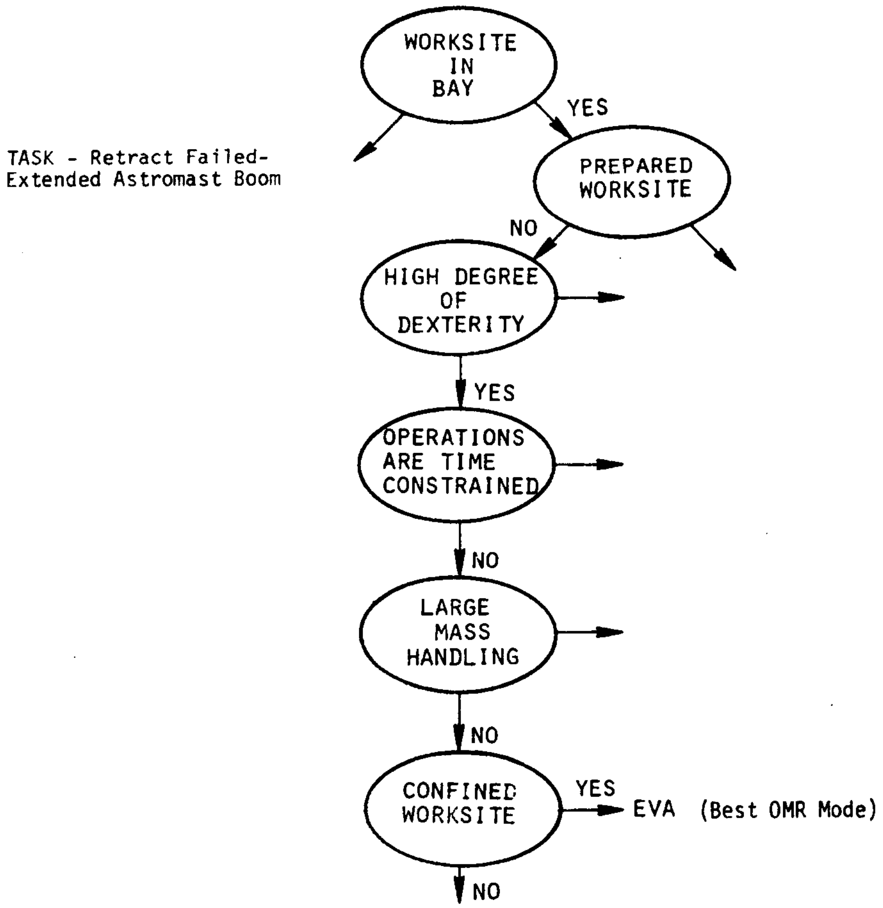
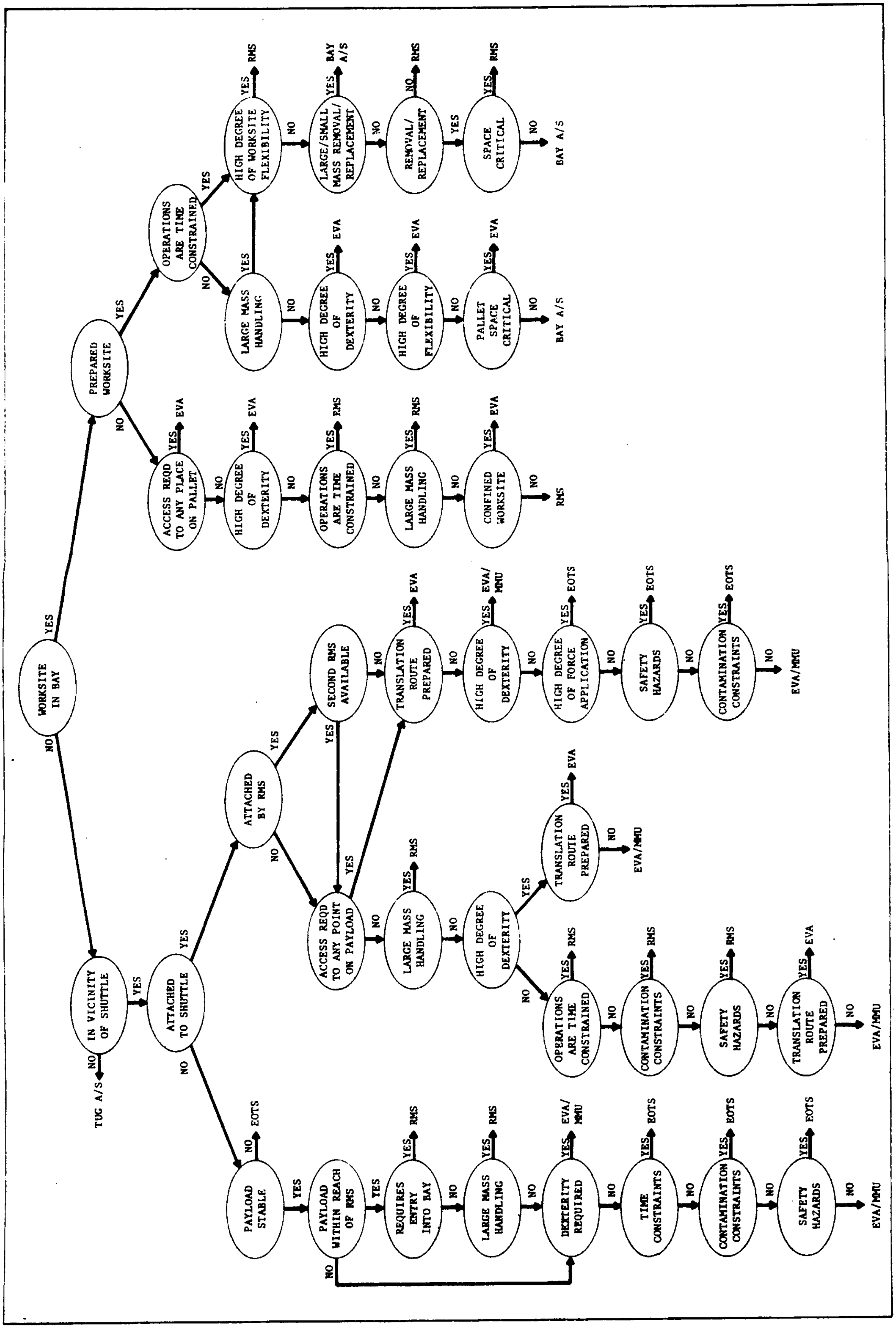


Figure 8-2: Simplified OMR Mode Selection Decision Tree

A mode selection decision tree for the general class of OMR tasks is presented as Figure 8-3. This tree provides a logical sequence of questions to guide the payload designer in the selection of the most appropriate OMR mode for a particular task. Detailed information required to answer the specific questions should be retreived from Table 8-1 or Sections 3.0 through 7.0.


WORKSITE IN BAY
YES
NO
PREPARED WORKSITE
OPERATIONS ARE TIME CONSTRAINED
LARGE MASS HANDLING
HIGH DEGREE OF WORKSITE FLEXIBILITY
RMS
LARGE/SMALL MASS REMOVAL/REPLACEMENT
BAY A/S
REMOVAL/REPLACEMENT
SPACE CRITICAL
HIGH DEGREE OF DEXTERITY
EVA
HIGH DEGREE OF FLEXIBILITY
PALLET SPACE CRITICAL
ACCESS REQD TO ANY PLACE ON PALLET
OPERATIONS ARE TIME CONSTRAINED
CONFINED WORKSITE
IN VICINITY OF SHUTTLE
TUG A/S
ATTACHED TO SHUTTLE
ATTACHED BY RMS
SECOND RMS AVAILABLE
TRANSLATION ROUTE PREPARED
EVA/MMU
HIGH DEGREE OF FORCE APPLICATION
EOTS
SAFETY HAZARDS
CONTAMINATION CONSTRAINTS
ACCESS REQD TO ANY POINT ON PAYLOAD
PAYLOAD STABLE
PAYLOAD WITHIN REACH OF RMS
REQUIRES ENTRY INTO BAY
DEXTERITY REQUIRED
TIME CONSTRAINTS

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